1900MNRAS..60..572S

the Society; G. W. Hill, On the extension of Delaunay's method in the Lunar theory to the general problem of planetary motion, presented by the author; W. E. Wilson, Astronomical and physical researches made at Daramona, Westmeath, presented by the author; Astronomischer Jahresbericht, Band 1, enthaltend die Literatur von 1899, presented by the editor, Dr. W. F. Wislicenus; Yerkes Observatory Publications, vol. i. (Burnham, General Catalogue of Double Stars), presented by the Observatory.

Description of the Durham Almucantar.
By Professor R. A. Sampson.

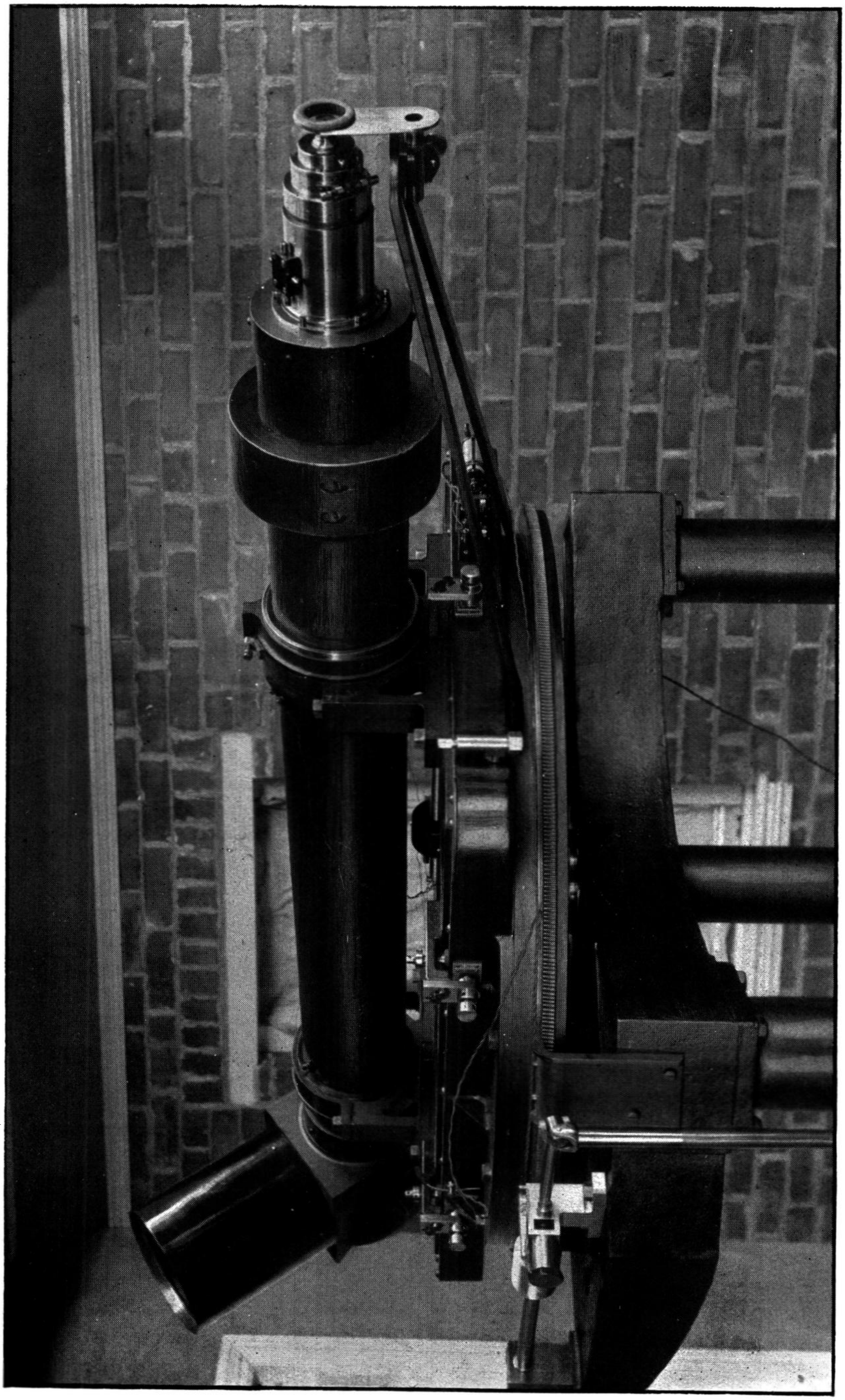
In the year 1884 Mr. S. C. Chandler set up at Cambridge, U.S.A., a transit instrument of a novel design, and made observations with it on time, latitude, and coordinates of stars for the space of about a year, in connection with Harvard College Observatory. A description of his instrument, its theory, and details of his observations are given by Mr. Chandler in vol. xvii. of the *Harvard Annals*. He named it Almucantar from the fact that it took transits across a horizontal circle, or almucantar, in place of across the meridian. Briefly, the principle of his design is to abolish adjustment and correction of the axis of rotation of his telescope by using the automatic action of gravity, and this he effects by clamping the telescope to a tray which floats on a trough containing mercury. Lateral motion of the float is prevented by stops, which are contrived so as not to interfere with the float taking up its own level, and accidental disturbance of the mercury is allowed to settle before the observation is made. If then the trough is rotated in azimuth, the axis of the telescope settles down to point always to the same horizontal circle on the sky, across which transits may be taken in the usual way. Every star which crosses this circle transits twice, once east and once west of the meridian, at azimuths which may be computed beforehand for the purpose of setting the instrument. From these we get two time observations, which determine the coordinates of the star, or, in the case of known stars, the instrumental errors.

Mr. Chandler's telescope was about 4 inches aperture and 43 inches focal length. His float was made of detached pieces of cherry wood, braced together with a brass frame, somewhat irregular in plan, like the letter E *minus* its middle stroke. The telescope hung over one side of the float, counterpoises being attached to the other side to keep it level. The whole floating piece weighed 31 lb. A second instrument, similar in all essentials to Mr. Chandler's, was made at the same time, and the two, I believe, are now in use, in the hands of Professor W. V. Brown of McKim Observatory, and Mr. Charles H. Rock-

Downloaded from http://mnras.oxfordjournals.org/ by guest on March 17, 2015

© Royal Astronomical Society • Provided by the NASA Astrophysics Data System

1900MNRAS..60..572S



THE DURHAM ALMUCANTAR.

Downloaded from http://mnras.oxfordjournals.org/ by guest on March 17, 2015

© Royal Astronomical Society • Provided by the NASA Astrophysics Data System

1900MNRAS..60..572S

well of Tarrytown, N.Y., for the ordinary services of a transit circle, but not, I think, directed to the solution of any special problem.

It was on the advice of Professor Turner and Dr. Common that the Curators of the University Observatory at Durham decided to set up an almucantar. Without their generous help I would often have been at a loss in carrying out the plan. To Dr. Common especially we are in most substantial debt. The *coudé* design is essentially his; moreover he gave us the 9-inch flat mirror, and he sketched the proper form of dome to use.

The instrument was made by Messrs. T. Cooke & Sons, and is, I think, a piece of work thoroughly worthy of the firm. Much of the detail of the design is theirs.

The house in which the almucantar is set up consists of two rooms, each 14 feet square, lying east and west of each other. Nearly the whole of the roof of the east room is built to run on rails over the roof of the west room, leaving a square opening which commands about 45° from the zenith in all directions. In the middle of this room, and clear of the floor, a pier 4 feet square is built up from the bottom of a pit 5 feet deep. This is topped with a massive stone, upon which the instrument is placed, the tube of the telescope lying horizontally with the eye-piece at a convenient height for a standing observer.

The floating parts weigh about 4 cwts., the whole instrument about 1 ton. The stand, trough, and float are made of cast iron; the telescope tube of riveted steel; the azimuth circle of brass.

The stand is a tripod with adjusting screws for feet; at its centre it carries a vertical axis which is guided by two finely turned gun-metal collars, 20 inches apart. The upper collar is cone-shaped, but the chief share of the weight of the moving parts is taken off this collar by a counterpoise. The axis carries, first, an azimuth circle, 40 inches in diameter, divided to 20′ and read by two verniers to 1′, and operated, when clamped, by a worm working in teeth cut in the edge of the circle. There are two slow-motion rods which can be worked when the observer is at the north and south positions respectively. To the frame of this circle the trough is bolted, rectangular in shape, with slightly rounded corners. Its outside measure is $38\frac{3}{4}$ inches long by $26\frac{3}{4}$ inches broad by $2\frac{1}{4}$ inches deep, and it is $\frac{5}{8}$ inch thick. It is provided with a tap for emptying it when necessary. There is $\frac{3}{4}$ inch clear space between the walls of the trough and those of the float on all sides, but to guard against accidental spilling of the mercury this space is all covered in except $\frac{1}{16}$ inch. To this portion of the instrument are attached a guard to keep the eye from touching the telescope when observing, electric switches, rheostat, &c., and two spirit levels for examining the verticality of the axis of rotation. On these levels 1 division = $4''\cdot2$ approximately. It is found that the stand changes very little from day to day, and that it is easy to keep the axis within $1''$ of the vertical.

Downloaded from http://mnras.oxfordjournals.org/ by guest on March 17, 2015

© Royal Astronomical Society • Provided by the NASA Astrophysics Data System

1900MNRAS..60..572S

In the trough is about 150 lb. of mercury, lying about $\frac{1}{4}$ inch deep beneath the float, and about 1 inch deep along the sides of the float.

The float is similar in shape to the trough, except that it is crossed by two longitudinal and three transverse walls, $\frac{3}{8}$ inch thick, to increase its rigidity. Its outside measure is 36 inches long by 24 inches broad by 2 inches deep, and it is $\frac{5}{8}$ inch thick. When floating, the top of its walls stands $\frac{1}{2}$ inch above the top of the trough. It is kept in its place by six stops. These stops have to fulfil the conditions of preventing lateral motion in two directions and rotation in azimuth, while offering no resistance to oscillations about a horizontal axis, and it is evident that these conditions are satisfied by a horizontal pressure at six points upon the plane of flotation. Such pressure is secured by substantial cast-iron brackets carried from the float outside the trough, and bearing by hard steel rounded adjustable points upon vertical agate faces attached to the outer walls of the trough. These points are screwed up so as to bear upon the agates at the level of the plane of flotation, and are screwed in so as to be just clear of simultaneous contact, and then a drop of oil is put upon the agate for the point to work upon. Four of the brackets are perforated by other screws, faced with leather, and moving vertically down upon the cover of the trough. The purpose of these screws is to limit or stop altogether the oscillations of the float; by screwing them down far enough the float may be lifted out of the mercury to any desired degree, and the instrument converted into an ordinary altazimuth.

Near the middle of the float terminals are fixed for attaching illuminating wires. These wires come from the sides of the trough, and in order that they shall not produce any pull upon the float, they are contrived in the form of a very weak spring which in its unconstrained position is clear of the terminal but as close to it as possible. The terminal is then screwed down upon the wire. When the leather-faced stops are screwed up, these terminals and the six steel points are the only solid points of connection between the float and the stand. The float is thus completely free to regain its old position after a disturbance.

At the two ends of the float are carried two Y's for bearing the telescope tube, each 2 inches broad and 22 inches from centre to centre. Each Y is provided with a clamp; the one near the eye end has also a slow-motion arrangement. When by help of this the telescope is set to the proper altitude (which in nearly every case is the apparent altitude of the pole), the other clamp is screwed down and the altitude cannot then be disturbed through a series of observations.

The telescope tube is a riveted steel tube, 6 inches internal diameter, $\frac{1}{16}$ inch thick, very stiff, and further stiffened by diaphragms. This carries at the O.G. end a cast-iron box, triangular in side elevation, the cell of the object glass being attached to one side of the triangle, and the cell of a plane

Downloaded from http://mnras.oxfordjournals.org/ by guest on March 17, 2015

© Royal Astronomical Society • Provided by the NASA Astrophysics Data System

1900MNRAS..60..572S

mirror to the hypotenuse. There is also a counterpoise for bringing the centre of gravity of this piece to lie in the axis of the telescope tube.

The object glass is 6 inches clear aperture. The mirror is necessarily larger, since it has to take the cone of rays obliquely at a point where it is hardly at all reduced in diameter.

The eye end is provided with the usual adjustments for focussing, and also with screws for making the wires horizontal. This is important, because it is only polar stars that transit all wires at their middle points. The eyepiece has no sliding motion; where it is necessary to extend the field of view it will be done by carefully changing the azimuth with the slow-motion handle. The lines in the focus are close together for chronograph use. Following Mr. Chandler's example, I have had them ruled upon a plate of glass, but this does not seem a success, and I am replacing the glass plate by the usual spider lines in five tallies of five lines each.

There is a large lead counterpoise upon the tube, near the eye end; and a smaller one, running on a screw, attached to the bed of the float.

The theory of this instrument is at first sight of a somewhat forbidding character, being in fact, for the case of the fiducial circle set upon the pole, the geometry of a spherical triangle which is approximately isosceles. It has, however, been put by Mr. Chandler into a workmanlike shape, which in the long run probably involves little more trouble than does the transit circle.

I have spoken of the fiducial circle passing through the pole. The telescope may indeed be used at any altitude, just as the transit circle may be used in any azimuth; but in all other cases the calculations involved appear to me quite prohibitive for continuous use, and I have not taken any pains to secure for my observing-room a range of sky much below the pole.

Just as with the transit circle, the fiducial line across which all transits are taken is the line traced out upon the sky by the line of collimation, but in the almucantar this fiducial line is horizontal. All that is necessary in order that a true horizontal circle should be traced is that the telescope and float should be one rigid piece which settles down after a disturbance to exactly the same position as before.

The procedure is generally as follows:—

We first of all compute for a star of given declination the azimuth and hour angle of its transits, and also the degree in which faults in the assumed declination, latitude, and instrumental setting on the pole would affect the time of a transit. For a large number of stars this is a comparatively heavy piece of work, but it may be done once for all for a given latitude, in a systematic way, for all declinations from 90° to the lowest that makes a transit.

Then, setting for any star at the computed azimuth and at a time shortly in advance of the time = R.A. $\pm$ computed hour

Downloaded from http://mnras.oxfordjournals.org/ by guest on March 17, 2015

© Royal Astronomical Society • Provided by the NASA Astrophysics Data System

1900MNRAS..60..572S

angle, we observe the correction to the computed time of transit, and this must be distributed among the various producing causes—incorrect coordinates of the star, errors in the clock, in assumed latitude, in assumed zenith distance of the fiducial horizontal circle. All this has been skilfully worked out by Mr. Chandler in a way that gives these quantities separately and with no great labour. I will only say here that we get the corrections of clock, latitude, and instrumental setting from fundamental stars, and that in order to correct the assumed coordinates of others, it is not necessary to take both their transits on the same night.

It thus appears that the instrument is a competitor of the transit circle. There are many members of the Society better qualified than I to criticise the performances of the transit circle, and the immense labour which has been spent upon the study of the best instruments makes it a thing very difficult to do; but seeing that, in spite of this, their performances are not wholly free from obscurity, there is evidently room for another instrument of equal or perhaps of greater accuracy, and presenting, as I hope to show, many advantages in build and in mode of use. I will consider shortly the most obvious of these, from their theoretical side.

In the transit circle the axis of rotation must lie horizontally in the meridian. In the almucantar it must be truly vertical. This it will be if the float recovers its old position exactly after a disturbance, such as must take place at each new setting in azimuth. Mr. Chandler considered that his almucantar recovered its position after disturbance within $\frac{1}{20}$ of a second of arc, and that a tilt of the trough, such as might be due to imperfect levelling, produced a tilt of the float in the opposite direction of about $\frac{1}{100}$ of the amount. My own experience, so far as it goes, is confirmatory of this exactness. I mounted a spirit level with which we take level error in transit circle observations upon the float, and then suddenly altered the tilt of the trough by more than $100''$ by screwing in one foot; the mercury ran to and fro beneath the float, but in about two minutes the spirit level settled down to exactly the same position as before. It was a favourable day, upon which the level was behaving steadily. The divisions of the level used are of value $1''\cdot5$, and it was read with a magnifier, in a good light. So far I have put no more searching test; but if we accept Mr. Chandler's measures, errors of this kind, occurring, if at all, as accidental errors in a single observation, must be dismissed as entirely impalpable, and by this we abolish two corrections which are theoretically inherent to any instrument of this class—namely, those which correspond to azimuth and level error in the transit circle.

Nor is this all. One of the obscurest points in the determination of zenith distances by the transit circle is the part played by anomalous departures from the mean refraction. It can only

Downloaded from http://mnras.oxfordjournals.org/ by guest on March 17, 2015

© Royal Astronomical Society • Provided by the NASA Astrophysics Data System

1900MNRAS..60..572S

be treated as an accidental error. But in the almucantar it is completely eliminated, at least so far as it is constant throughout one night. For it acts in the same way as an error in the assumed zenith distance of the line of collimation, and the sum of the two is determined from fundamental stars each night, and is, of course, treated as a single error.

A fourth advantage is that we do not employ a divided circle for determining the star's position. Two transits, east and west, give the two coordinates. This amounts to replacing error of reading a circle by error of taking a transit, and errors proper to a circle itself by errors of a clock. Were this the only advantage the almucantar offered I think it would be a great one. To take only one kind of error inherent to a divided circle—the actual errors of the divisions themselves. In the life of the Greenwich Transit Circle these have been estimated at different times at five different amounts, and the last-adopted amounts differ from those used from 1868–79, in five cases out of sixty by quantities not less than $0''{\cdot}2$, and in sixteen cases by quantities not less than $0''{\cdot}1$, and from those used from 1880–96 in three cases by not less than $0''{\cdot}2$ and in nineteen cases by not less than $0''{\cdot}1$. These differences are no doubt small, even when considered as two deliberate measures of the same quantities; yet they are comparable with the probable error of the clock as deduced from a fairly long night's observations; they are moreover only one and that the least obscure and the most liable to experiment of the errors to which a divided circle is subject. Others are more competent to judge this point than I, but it seems to me a substantial gain to replace these errors by a repetition of the errors of clock and transit, even though, as will appear presently, declinations are not determined by an almucantar with equal rigour over its whole range.

A fifth error which is entirely eliminated is that of flexure of the telescope tube. This again is a very obscure point in transit-circle observations; at Greenwich it is allowed for through the R—D discordance, but some writers deny that the R—D discordance is a function of the Zenith Distance at all.*

There are other advantages which, though not so easy to assess, appear to me to carry considerable weight. The first of these is the homogeneity of the observations. In the transit circle declination is found by one species of observation, R.A. and clock error by another, and both must be combined with an altogether different series, taken in other ways and at other times for measuring other instrumental errors. With proper care the faults of such a plan are no doubt small, but they render it almost impossible to locate the more minute and obscure errors with which the final result is affected. Now with the almucantar both coordinates of the star and all instrumental errors are determined from a perfectly homogeneous system of transits. This must conduce to the removal of obscurities.

* Eastman, *Ast. Journal*, vol. xxi. p. 8.

Downloaded from http://mnras.oxfordjournals.org/ by guest on March 17, 2015

© Royal Astronomical Society • Provided by the NASA Astrophysics Data System

1900MNRAS..60..578S

The last advantage I would mention is the attitude of the observer. It is certain that no one would adopt, unless he were compelled, the attitudes enforced by the ordinary observing couch. With the almucantar as we have it the observer looks horizontally before him, standing in a normal attitude, which is the same for all stars.

Against these advantages must be set certain disqualifications. The chief is the limitation of the field of work: no star below 19° 32′ N. declination will transit the circle across which my observations are to be made, so that, for example, the Sun, Moon, and planets cannot be continuously observed.

Again, there is a peculiarity of the observations which is not found in the transit circle: different stars do not transit the wires at the same angle; each cuts them at an angle equal to its own hour angle. What effect this may have upon the transits must be discovered hereafter.

I have said that the net result of an almucantar observation is an equation connecting observed correction to a computed time and desired corrections to clock, R.A., declination, &c. Hence, if we chart the reciprocals of the coefficients with which these quantities appear in this equation, we get an immediately comprehensible view of the amount of error involved by a given error in taking a transit, supposing that error allocated exclusively to each of the unknowns in turn.

The accompanying chart (Plate 19) shows these quantities, and also the azimuth setting for any declination. The errors shown are such as would be produced by an error of $0^{s}\cdot1$ in a transit; reading abscissæ for declination, we see, for example, that an error of $0^{s}\cdot1$ in the transit of a star of declination 30° would introduce an error of $0''\cdot48$ in a latitude determined from this observation, if we simultaneously took all the other quantities as correct. Hence we see that latitude, which it may be convenient to treat as a variable, is found with very great rigour from observations of south stars. In the same way the collimation error, being a correction to assumed zenith distance, is found fully as exactly from transits of north stars. Clock error will be best found from quicker-moving stars near the prime vertical.

The precision of determinations of declination varies considerably. It is at first high, but falls off rather rapidly. An error of $0^{s}\cdot1$ in a transit implies an error of $0''\cdot3$ at +20°, $0''\cdot8$ at +30°, $1''\cdot3$ at +40°, $1''\cdot6$ at +50°, $2''\cdot0$ at +70°, after which it is nearly constant. Some comparison of these with the transit circle may be made. For example, at Greenwich in 1897 the N.P.D. of *Polaris* was measured seventy times at its upper transit, and the average discordance of the mean from individual results was $\pm0''\cdot8$, and this may be taken as a fair average of the Greenwich measures of N.P.D. At the same time if we take any long series of transits of quick-moving stars by the same observer, the average discordance from the mean indicated clock error was $\pm0^{s}\cdot04$ or $\pm0^{s}\cdot05$. If then I should succeed in taking transits

Downloaded from http://mnras.oxfordjournals.org/ by guest on March 17, 2015

© Royal Astronomical Society • Provided by the NASA Astrophysics Data System

1900MNRAS..60..578S

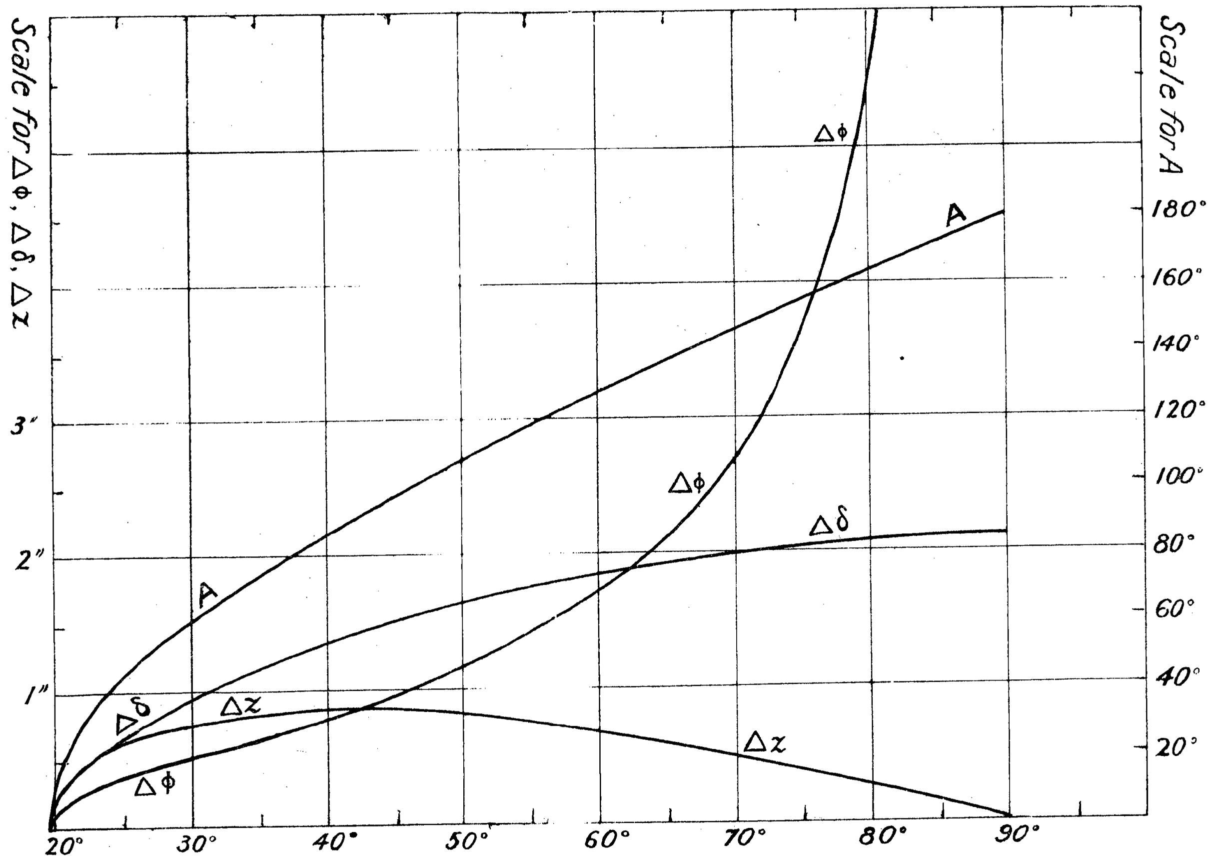


Chart of Almucantar Constants for Latitude of Durham Observatory (54° 46′ 6″·2 N).

Abscissa = declination of object.

Ordinates, A = azimuth at transit.

Δδ = error in deduced declination for $0^s \cdot 1$ error in transit.

Δφ = ,, ,, ,, latitude ,, ,, ,, ,, ,,

Δz = ,, ,, ,, collimation ,, ,, ,, ,, ,,

Downloaded from http://mnras.oxfordjournals.org/ by guest on March 17, 2015

© Royal Astronomical Society • Provided by the NASA Astrophysics Data System

1900MNRAS..60..578S

as correct as those of Greenwich, they would, of course, give Right Ascensions of equal exactness, while errors in declinations would be less from 20° to 50°, and above that somewhat greater. It is with hesitation that I give this estimate, because such forecasts are not of much value, and are open to the objection of seeming to claim credit for a status that has hereafter to be justified. My purpose is very different from that; it is to show that *prima facie* the almucantar has claim to be admitted of as great or greater precision than the transit circle, though over a somewhat more restricted range. It is not to be expected that it will prove an exception to invariable experience with new instruments, and yield results of the first rank of accuracy, without the cost of much thought and labour, although Mr. Chandler's early success with it is encouraging.

It is my intention in the first instance to test its performances by re-observing many times the transits of *Nautical Almanac* stars, of which 121 cross our circle of observation, with the intention of doing everything to increase, if possible, the fidelity of such fundamental points. Even if experience should hereafter suggest some other line as more profitable, I think time would be gained on the whole by first establishing thoroughly the character of the instrument and finding out its peculiarities by such a research.

The Effects of Stellar Rotation upon Spectrum Lines.

By A. Fowler.

The possible modification of the lines in a stellar spectrum by a rapid rotation of the star was first pointed out by Sir William Abney in 1877.* Provided that the axis is not directed towards the Earth, it is evident that the effect of rotation will be to broaden all the lines of the spectrum, since rays proceeding from the central meridian of the star disc will suffer no displacement on account of this motion, while those from the approaching and receding portions will be displaced by varying amounts towards the more and less refrangible ends of the spectrum respectively. Abney suggested that the finer lines of a spectrum might in this way be caused to disappear, and that the velocity of rotation might be derived from the observed amount of broadening. In the same year Vogel investigated the distribution of intensity in a line broadened in this manner,† but spectra satisfying the conditions were then unknown.

Many spectra in which all the lines are wide and ill defined have since been recorded, and in the case of α *Aquilæ* rotation has been adopted by Pickering, Lockyer, and Vogel as

* *Monthly Notices*, vol. xxxvii. p. 278.
† *Ast. Nach.* Bd. 90, p. 71.

Downloaded from http://mnras.oxfordjournals.org/ by guest on March 17, 2015

© Royal Astronomical Society • Provided by the NASA Astrophysics Data System